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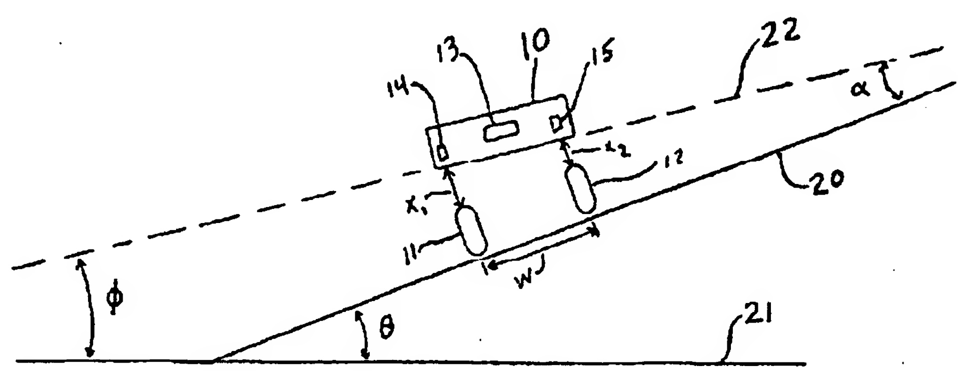

(57) Abstract: The measurement lateral acceleration of a vehicle is compensated for the gravity component introduced in accelerometer measurements resulting from a banked road and/or vehicle rolling motion. In yaw stability control systems, performance does not have to be desensitized to prevent false activations for banked turns, for example. In addition, the present invention provides an estimate of bank angle which can be used in other control systems (such as the active suspension system) to improve their performance. By comparing an estimated horizontal lateral acceleration based on overall vehicle dynamics (i.e., not using the accelerometer) with the measured lateral acceleration in the plane of the vehicle, the displacement angle of the vehicle plane (i.e., measurement plane) to horizontal is estimated. The displacement angle is used to determine the road bank angle and/or the lateral acceleration in the road plane.

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LATERAL ACCELERATION SENSOR COMPENSATION FOR AN INCLINED MEASUREMENT PLANE

BACKGROUND OF THE INVENTION

This invention relates in general to electronically-controlled vehicular active braking and suspension systems. In particular, this invention is concerned with providing compensation for measurement errors in lateral acceleration sensors when the measurement plane of the sensor is inclined with respect to the road surface, such as in a banked turn or when the vehicle has a rolling motion.

Electronically-controlled vehicular braking systems can include anti-lock braking (ABS), traction control (TC), and yaw stability control (YSC) functions. These three function can be combined into a vehicle stability control (VSC) system. In such braking systems, sensors deliver input signals to an electronic control unit (ECU). The ECU sends output signals to electrically activated devices to apply, hold, and dump (relieve) pressure at wheel brakes of a vehicle. Electrically activated valves and pumps are typically used to control fluid pressure at the wheel brakes. Such valves and pumps can be mounted in a hydraulic control unit (HCU). The valves can include two-state (on/off or off/on) solenoid valves and proportional valves.

Electronically-controlled suspension systems can include semi-active suspension systems and active suspension systems to provide active damping for a vehicle. In such suspension systems, sensors deliver input signals to an electronic control unit (ECU). The ECU sends output signals to electrically activated devices

to control the damping rate of the vehicle. Such devices include actuators to control fluid flow and pressure. The actuators typically include electrically activated valves such as two-state digital valves and proportional valves.

Most YSC systems include a lateral accelerometer mounted on the vehicle which measures acceleration in the plane of the vehicle body or frame. The accelerometer output corresponds to the sum of components of all accelerations in its measurement plane. The lateral acceleration measurement is used together with other sensor information (e.g., steering angle and yaw rate) to determine vehicle sideslip which may then be controlled in a desired manner for YSC operation. For a vehicle with no roll motion on a flat road surface, the lateral acceleration measurement has good accuracy. Any roll motion or traveling on a banked road surface, however, can combine to cause the measurement plane of the accelerometer to become inclined with respect to the road surface plane, thereby resulting in a discrepancy between the measured lateral acceleration and the actual lateral acceleration in the road plane. This error can be undesirable because typical YSC control strategies depend upon aknowledge of lateral acceleration in the road plane. For many YSC systems, the vehicle models are based upon planar dynamics (i.e., a rigid, non-suspended body on a flat plane) which do not include vehicle roll or travel on a banked surface.

When a vehicle is on a banked road surface (such as a curve) or when the vehicle body rolls significantly, gravity is no longer perpendicular to the accelerometer's measurement plane. This adds in a gravitational component which causes errors in the sideslip calculations and could lead to false activations of the YSC system.

The existing way of overcoming this problem is to reduce the sensitivity (degrade the performance) of a YSC system over all conditions – whether the vehicle rolls, is on a banked curve, or a curve with neither.

SUMMARY OF THE INVENTION

The present invention advantageously compensates for the gravity component (due to a banked road and/or a vehicle roll motion) so that measured acceleration is corrected before being used by the YSC system. YSC performance does not have to be desensitized to prevent false activations for banked turns, for example. In addition, the present invention provides an estimate of bank angle which can be used in other control systems (such as the active suspension system) to improve their performance.

In one aspect of the invention, a method of determining road-plane lateral acceleration in a vehicle having a suspension sensor and an accelerometer comprises measuring a roll angle in response to the suspension sensor. A vehicle-plane lateral acceleration is measured in response to the accelerometer. Horizontal lateral acceleration is estimated independently of the accelerometer. An estimated bank angle is determined in response to a relationship between the roll angle, the measured vehicle-plane lateral acceleration, and the estimated horizontal lateral acceleration. The road-plane lateral acceleration is determined in response to the estimated bank angle and the measured vehicle-plane lateral acceleration.

Various objects and advantages of this invention will become apparent to those skilled in the art from the following detailed description of the preferred embodiment, when read in light of the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram defining various angles for a vehicle with roll on a banked surface.

Figure 2 is a plot showing the relationship of acceleration vectors for the vehicle of Figure 1.

Figure 3 is a flowchart of a preferred embodiment of the invention for estimating the bank angle of an inclined road surface and determining a road-plane lateral acceleration.

Figure 4 is a block diagram showing one preferred embodiment for determining an estimated horizontal lateral acceleration.

Figure 5 is a schematic diagram of a first embodiment of an integrated vehicular control system for implementing the present invention.

Figure 6 is a schematic diagram of a second embodiment of an integrated vehicular control system for implementing the present invention.

Figure 7 is a schematic diagram of a third embodiment of an integrated vehicular control system for implementing the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figure 1, an automotive vehicle includes a body or frame portion 10 connected by a suspension (not shown in Figure 1) to a pair of front wheels 11 and 12. An accelerometer 13 is mounted on body portion 10, preferably at or close to the center of gravity of the vehicle. The suspension associated with each wheel has respective height sensors 14 and 15 providing respective height

measurements x_1 and x_2. The vehicle has a track width W between wheels 11 and 12.

The vehicle travels on a road surface shown as banked at an inclined plane 20 with respect to horizontal plane 21. The incline angle is referred to as bank angle θ. In addition, the vehicle is shown with roll in a roll plane 22 inclined to the road surface at a roll angle α. The roll plane or measurement plane of the vehicle makes a displacement angle ϕ with respect to horizontal plane 21.

Figure 2 shows the relationship of acceleration vectors for the vehicle of Figure 1. The two sources of acceleration are the actual lateral acceleration a_y acting in the horizontal plane and gravity g acting in the vertical plane. The accelerometer responds to components of these accelerations projected into its measurement plane 22. Specifically, a gravity component 23 and an a_y component 24 are projected into plane 22. Their vector sum results in a measured lateral acceleration a_m. However, what is really desired for purposes of YSC functions is a control-plane or vehicle-plane lateral acceleration a_p which is a projection of the a_y component into road plane 20 (with no contribution from the gravity component).

On a flat road surface with no vehicle roll, measured lateral acceleration a_m should equal a_y. Any difference between a_m and a_y is a reflection of the displacement angle between the measurement plane and horizontal (i.e., the sum of the bank angle and the roll angle). The present invention compares measured lateral acceleration a_m with an estimated value of a_y determined independently of the accelerometer measurement in order to determine the angle of the measurement plane. Once the angle of the measurement plane is known, the a_y component of the measured lateral acceleration a_m in the horizontal plane can be determined. Since the angle of the measurement plane and the roll angle are known, the a_y component

can be projected into the road plane and the value of vehicle-plane lateral acceleration a_p is determined. Furthermore, the intermediate determination of the bank angle is useful in its own right for many other control purposes.

Resolving the main acceleration vectors into the measurement plane gives

$$a_m = g\sin\phi + a_y\cos\phi. \qquad \text{Eq. 1}$$

Using an estimated value for a_y (determined, for example, by modeling a_y as a function of yaw rate and slip rate as described in connection with Figure 4 below), and taking a value of 1 as an approximation of cos ϕ, Equation 1 is solved for ϕ as follows:

$$\phi = \arcsin\left(\frac{a_m - est(a_y)}{g}\right) \qquad \text{Eq. 2}$$

Roll angle is determined in this example from suspension height measurements:

$$\alpha = \arctan\left(\frac{x_1 - x_2}{W}\right) \qquad \text{Eq. 3}$$

The relationship between measurement (or displacement) angle ϕ, roll angle α, and bank angle θ is:

$$\theta = \phi + \alpha \qquad \text{Eq. 4}$$

Combining Equations 2, 3, and 4 yields:

$$\theta = \arcsin\left(\frac{a_m - est(a_y)}{g}\right) + \arctan\left(\frac{x_1 - x_2}{W}\right) \qquad \text{Eq. 5}$$

Thus, an estimated bank angle is determined in response to measured lateral acceleration, estimated lateral acceleration, and measured roll angle. Since the displacement of the measurement plane rarely would exceed about 20°, the approximation of $\cos\phi$ being equal to 1 is good to within about 94% and the value for bank angle θ is an excellent approximation.

Now that a value for ϕ is available, Equation 1 can be solved for an actual value of a_y as follows:

$$a_y = \frac{a_m - g\sin\phi}{\cos\phi} \quad \text{Eq. 6}$$

This actual value is projected into the road plane as follows:

$$a_p = a_y \cos\theta \quad \text{Eq. 7}$$

Combining Equations 3, 4, 6 and 7 yields:

$$a_p = \frac{a_m - g\sin\phi}{\cos\phi}\cos\left(\phi + \arctan\left(\frac{x_1 - x_2}{W}\right)\right) \quad \text{Eq. 8}$$

In terms of θ and α, Equation 8 can be rewritten as:

$$a_p = \frac{a_m - g\sin(\theta-\alpha)}{\cos(\theta-\alpha)}\cos(\theta) \quad \text{Eq. 9}$$

Thus, a lateral acceleration value is obtained within the reference frame of the YSC vehicle models.

The present invention can be used to determine bank angle under all conditions and not just while in a turn.. When traveling straight on a banked or crowned road surface, estimated lateral acceleration would be zero but acceleration of gravity would create a nonzero lateral acceleration measurement in the accelerometer. The difference can be used to give an estimate of bank angle.

Preferred methods of the invention will be summarized with reference to the flowchart of Figure 3. In step 25, the vehicle roll angle α is measured based on information from one or more sensors in the suspension system. For example, strut height sensors can be used together with Equation 3. In step 26, the vehicle-plane lateral acceleration is measured. Horizontal lateral acceleration is estimated in step 27 based upon other information available to the vehicle control system. In step 28,

bank angle may be determined as a function of roll angle, measured vehicle-plane acceleration, and estimated horizontal lateral acceleration. Road-plane lateral acceleration is determined as a function of bank angle and measured vehicle-plane lateral acceleration in step 29. If a value of the bank angle is not desired for any other purpose, then step 28 may alternatively determine just the displacement angle ϕ and step 29 determines road-plane lateral acceleration using terms of displacement angle and roll angle. In either case, the road-plane lateral acceleration is provided to a YSC algorithm for controlling vehicle stability, for example. It may be desirable to pass the value of the bank angle to the YSC algorithm as well.

Figure 4 shows a preferred method of estimating horizontal lateral acceleration using a "bicycle" model 30. A steering angle signal δ from a steering angle sensing circuit (not shown) and a vehicle speed signal V from a speed sensing circuit (e.g., including wheel rotation sensors) are provided to bicycle model 30. Bicycle model 30 is of a known type for relating various vehicle performance characteristics and for purposes of the present invention is set up to generate an estimated lateral acceleration $est(a_y)$ in response to V and δ. Bicycle model 30 may, for example, model lateral acceleration based on yaw rate and slip rate according to the equation $a_y = V\left(r + \dot{\beta}\right)$, where r is yaw rate and $\dot{\beta}$ is slip rate.

Other methods of estimating lateral acceleration are known and could equally well be used in the present invention. Furthermore, the present invention is applicable to vehicle operation on a flat road as well as on a road having an adverse or opposite camber.

Several embodiments of integrated suspension and active braking systems will be described with reference to Figures 5-7. These systems are particularly well suited for implementing the present invention.

A first embodiment of a vehicular control system according to the present invention is indicated generally at 100 in Figure 6. The control system 100 is particularly adapted to control fluid pressure in an electronically-controlled vehicular braking system and an electronically-controlled vehicular suspension system. The braking system can include anti-lock braking, traction control, and yaw stability control functions. The suspension system can include active damping functions.

The control system 100 includes a first electronic control unit (ECU) 102. The first ECU 102 includes a signal processor 104 and a braking algorithm 106. Various sensors 108 strategically placed in a vehicle deliver input signals 110 to the signal processor 104. Specifically, a lateral acceleration sensor 112 delivers an input signal 114 to the signal processor 104. A longitudinal acceleration sensor 115 delivers an input signal 116 to the signal processor 104. A steering wheel sensor 117 delivers an input signal 118 to the signal processor 104. A yaw rate sensor 120 delivers an input signal 122 to the signal processor 104. Depending upon the braking functions of the braking system, some of the above-listed sensors and their associated input signals may be deleted and others may be added. For example, a braking system that provides only ABS and TC functions may not require some of the above-listed sensors.

The signal processor 104 delivers transfer signals 124 to the braking algorithm 106. The braking algorithm 106 delivers output signals 126 to a hydraulic control unit (HCU) 128. The HCU 128 can include electromechanical components

such as solenoid and/or proportional valves and pumps (not illustrated). The HCU 128 is hydraulically connected to wheel brakes and a source of brake fluid, neither of which is illustrated.

The control system 100 also includes a second ECU 130. The second ECU 130 includes a signal processor 132 and a suspension algorithm 134. Various sensors 135 strategically placed in a vehicle deliver input signals 136 to the signal processor 132. Specifically, a suspension state sensor 137 delivers an input signal 138 to the signal processor 132. A suspension displacement sensor 139 delivers an input signal 140 to the signal processor 132. A relative velocity sensor 141 delivers an input signal 142 to the signal processor 132. An upsprung mass acceleration sensor 143 delivers an input signal 144 to the signal processor 132. Depending upon the performance requirements of suspension system, some of the above-listed sensors may be deleted and others may be included.

The second signal processor 132 delivers transfer signals 145 to the suspension algorithm 134. The first signal processor 104 delivers transfer signals 146 to the suspension algorithm 134. The suspension algorithm 134 delivers output signals 148 to suspension actuators 150, only one of which is illustrated. The actuators 150 are electrically controlled devices such as dampers that vary and control a damping rate of a vehicle. An actuator 150 can include electromechanical components such as solenoid and proportional valves.

Information from the vehicular braking system can be shared with the vehicular suspension system. For example, ECU 102 can direct information to ECU 130. One example of transferred information from the braking system to the suspension system is the transfer signal 146 from signal processor 104 to suspension algorithm 134. A second example of transferred information from the braking

system to the suspension system is indicated by transfer signal 152, wherein information from the braking algorithm 106 is directed to the suspension algorithm 134.

Information from the suspension system can also be shared with the braking system. For example, ECU 130 can direct information to ECU 102. One example of transferred information from the suspension system to the braking system is a transfer signal 154 to a load and load transfer detector 155. Another example is a transfer signal 156 to a turning detector 157. Yet another example is a transfer signal 158 for surface and mismatch tire detector 159.

The control system 100 can be configured in various manners to share information from ECU 102 to ECU 130, and vice versa. In one example, an ECU 102 for the braking system that receives inputs signals 114, 116, 118 and 122, for lateral acceleration, longitudinal acceleration, steering wheel angle, and yaw rate, respectively, can transfer these input signals to ECU 130 for the suspension system. The signal processor 104 of ECU 102 can send transfer signal 146 to the suspension algorithm 134.

In another example, if lateral acceleration and steering wheel angle signals 114 and 122 are not available to the braking system, a turning detector signal can be generated by ECU 130 and transmitted to ECU 102 to improve braking performance. If an electronically controlled suspension system is integrated with an electronically controlled ABS/TC braking system, turning of the vehicle can be detected by the suspension system, thereby generating a turning detector signal that is transmitted to a braking system that does not receive signals from lateral acceleration and steering wheel angle sensors. A turn detection signal to the braking

system via ECU 102 can enhance braking performance, particularly during braking-in-turn and accelerating-in-turn.

A second embodiment of a control system for controlling vehicular braking and suspension functions is indicated generally at 200 in Figure 7. Elements of control system 200 that are similar to elements of control system 100 are labeled with like reference numerals in the 200 series.

Control system 200 also includes an ABS/TC algorithm 206A and a VSC algorithm 206B in place of the braking algorithm 106 of control system 100. Signal processors 204 and 232 may be placed separately from their respective algorithms 206A, 206B, and 230, or they may be located in common ECU's (not illustrated in Figure 7). Transfer signal 270 between ABS/TC algorithm 206A and VSC algorithm 206B is provided. Transfer signal 272 for load and load transfer is provided to the VSC algorithm 206B. Transfer signal 273 from the signal processor 204 is provided to the VSC algorithm 206B. Transfer signal 274 for the surface and mismatch tire detector is provided to the VSC algorithm 206B. Transfer signal 275 is provided from the VSC algorithm 206B to the suspension algorithm 234. Output signal 276 is sent from the VSC algorithm 206B to the HCU 228.

Various calculations can be made for the suspension system. For example, relative velocity can be calculated from suspension displacement if it is not directly measured. A vehicle load and load transfer signal 154, 254 can also be calculated or enhanced from a lateral acceleration signal 114, a longitudinal acceleration signal 118, and a steering wheel angle signal 122 when these are available.

A load and load transfer signal 154, 254 is used by the braking algorithms to enhance braking torque proportioning and apply and dump pulse calculations.

A turning detector signal 156, 256 (roll moment distribution) can be used to optimize vehicle handling before VSC activation and enhance brake torque distribution calculation during VSC activation.

A road surface roughness and tire mismatching signal 158, 258 can be detected from suspension states and used by ABS/TC and VSC systems.

Braking/traction status information from the wheels can also be used to enhance braking algorithms by predicting pitch and roll motion in advance.

Suspension algorithms and braking algorithms can be embodied in separate ECU's 102 and 130 as illustrated in Figure 6. In other embodiments, the suspension and braking algorithms can be integrated into a single electronic control unit.

If steering wheel angle signal 122, 222 and/or a lateral acceleration signal 114, 214 are available, then split mu detection in ABS and TC algorithms (for stand alone ABS and TC systems) can be improved.

In other examples, ECU 102 can only receive information from ECU 130. Thus, various input signals from the suspension system can be transferred to the braking system, but no signals are transferred from the braking system to the suspension system.

In yet other examples, ECU 130 can only receive information from ECU 102. Thus, various input signals from the braking system can be transferred to the suspension system, but no signals are transferred from the suspension system to the braking system.

A third embodiment of a control system for controlling vehicular braking and suspension functions is indicated generally at 300 in Figure 8. In control system 300, a single ECU 302 receives inputs signals 304 from various sensors 306 strategically placed in a vehicle. A signal processor 308 may be incorporated in the

ECU 302 that delivers transfer signals 310 to an algorithm 312. The algorithm 312 delivers output signals 314 to a HCU 328 to provide a desired brake response. The algorithm 312 also delivers output signals 316 to actuators 350 to provide a desired suspension response. Control system 300 may be referred to as a totally integrated system for controlling vehicular braking and suspension.

In accordance with the provisions of the patent statutes, the principle and mode of operation of this invention have been explained and illustrated in its preferred embodiment. However, it must be understood that this invention may be practiced otherwise than as specifically explained and illustrated without departing from its spirit or scope.

CLAIMS

What is claimed is:

1. A method of determining the lateral acceleration of a vehicle comprising the steps of:

measuring the lateral acceleration of the vehicle to generate a measured lateral acceleration signal, said measured lateral acceleration signal having a value different than the actual lateral acceleration of the vehicle;

measuring at least one suspension operating characteristic of a portion of the vehicle suspension system, said operating characteristic at least in part representative of the roll tendency of the vehicle; and

determining a corrected lateral acceleration value as function of the measured lateral acceleration value and said one suspension operating characteristic.

2. The method according to claim 1 and further including the step of utilizing said modified lateral acceleration value in a braking control algorithm operable in at least one of a plurality of states including anti-lock control, traction control, and yaw stability control in order to enhance the braking, traction or stability characteristics of the vehicle.

3. The method according to claim 1 and further including the step of using said corrected lateral acceleration value in a suspension control algorithm to enhance the ride quality or handling of the vehicle.

4. A method of estimating a bank angle in a vehicle having a suspension sensor and an accelerometer, said method comprising the steps of:

measuring a roll angle in response to said suspension sensor;

measuring a vehicle-plane lateral acceleration in response to said accelerometer;

estimating horizontal lateral acceleration independently of said accelerometer; and

determining an estimated bank angle in response to a relationship between said roll angle, said measured vehicle-plane lateral acceleration, and said estimated horizontal lateral acceleration.

5. The method of claim 4 wherein said relationship is comprised of:

$$\theta = \arcsin\left(\frac{a_m - est(a_y)}{g}\right) + \alpha$$

where θ is said bank angle, α is said roll angle, $est(a_y)$ is said estimated horizontal lateral acceleration, a_m is said measured vehicle-plane lateral acceleration, and g is a gravitational constant.

6. The method of claim 4 wherein said estimated horizontal lateral acceleration is determined in response to a measured vehicle speed and a measured steering angle.

7. The method of claim 4 wherein said suspension sensor is comprised of height sensors on opposite lateral sides of said vehicle.

8. A method of determining road-plane lateral acceleration in a vehicle having an accelerometer, said method comprising the steps of:

measuring a vehicle-plane lateral acceleration in response to said accelerometer;

estimating horizontal lateral acceleration independently of said accelerometer;

determining an estimated displacement angle in response to a relationship between said measured vehicle-plane lateral acceleration and said estimated horizontal lateral acceleration; and

determining said road-plane lateral acceleration in response to said estimated displacement angle and said measured vehicle-plane lateral acceleration.

9. The method of claim 8 wherein said estimated displacement angle is determined according to a formula substantially equal to:

$$\phi = \arcsin\left(\frac{a_m - est(a_y)}{g}\right)$$

where ϕ is said displacement angle, $est(a_y)$ is said estimated horizontal lateral acceleration, a_m is said measured vehicle-plane lateral acceleration, and g is a gravitational constant.

10. The method of claim 8 wherein said displacement angle is comprised of a roll angle and a bank angle, and wherein said vehicle has a suspension sensor for measuring said roll angle.

11. The method of claim 10 wherein said road-plane lateral acceleration is determined according to a formula substantially equal to:

$$a_p = \frac{a_m - g\sin\phi}{\cos\phi}\cos(\phi+\alpha)$$

where a_p is said road-plane lateral acceleration, a_m is said measured vehicle-plane lateral acceleration, ϕ is said displacement angle, α is said roll angle, and g is a gravitational constant.

12. A method of determining road-plane lateral acceleration in a vehicle having a suspension sensor and an accelerometer, said method comprising the steps of:

measuring a roll angle in response to said suspension sensor;

measuring a vehicle-plane lateral acceleration in response to said accelerometer;

estimating horizontal lateral acceleration independently of said accelerometer;

determining an estimated bank angle in response to a relationship between said roll angle, said measured vehicle-plane lateral acceleration, and said estimated horizontal lateral acceleration; and

determining said road-plane lateral acceleration in response to said estimated bank angle and said measured vehicle-plane lateral acceleration.

13. The method of claim 12 wherein said relationship is comprised of:

$$\theta = \arcsin\left(\frac{a_m - est(a_y)}{g}\right) + \alpha$$

where θ is said bank angle, α is said roll angle, $est(a_y)$ is said estimated horizontal lateral acceleration, a_m is said measured vehicle-plane lateral acceleration, and g is a gravitational constant.

14. The method of claim 12 wherein said road-plane lateral acceleration is determined according to a formula substantially equal to:

$$a_p = \frac{a_m - g\sin(\theta - \alpha)}{\cos(\theta - \alpha)}\cos(\theta)$$

where a_p is said road-plane lateral acceleration, a_m is said measured vehicle-plane lateral acceleration, θ is said bank angle, α is said roll angle, and g is a gravitational constant.

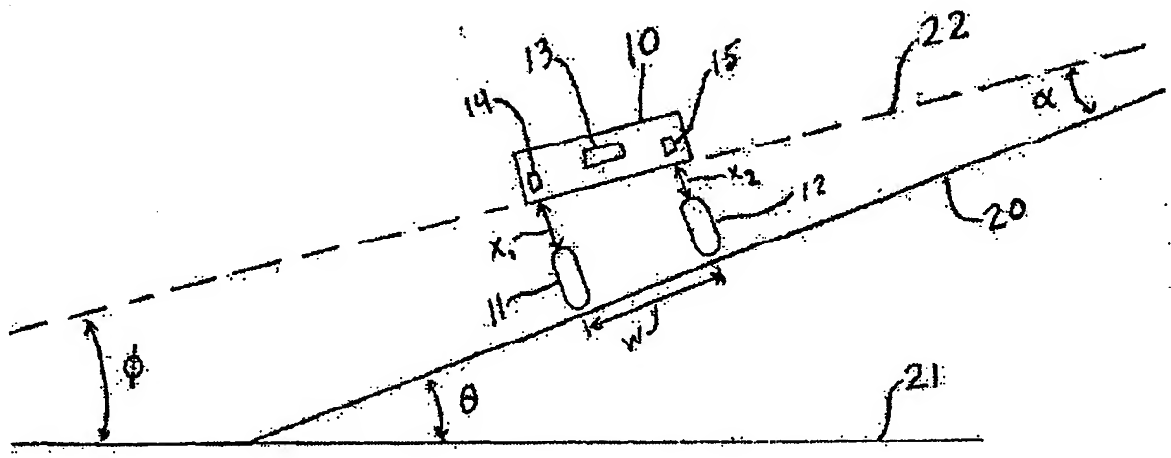
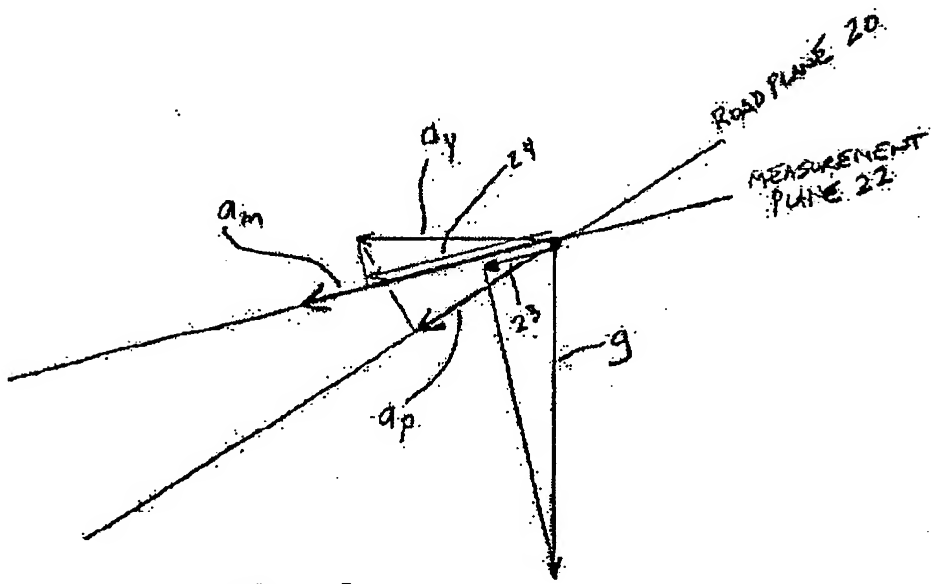

13
10
15
22
14
x_2
12
20
α
x_1
11
w
ϕ
θ
21

Fig. 1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MEASUREMENT PLANE 22
a_y
24
a_m
23
g
a_p

Fig. 2

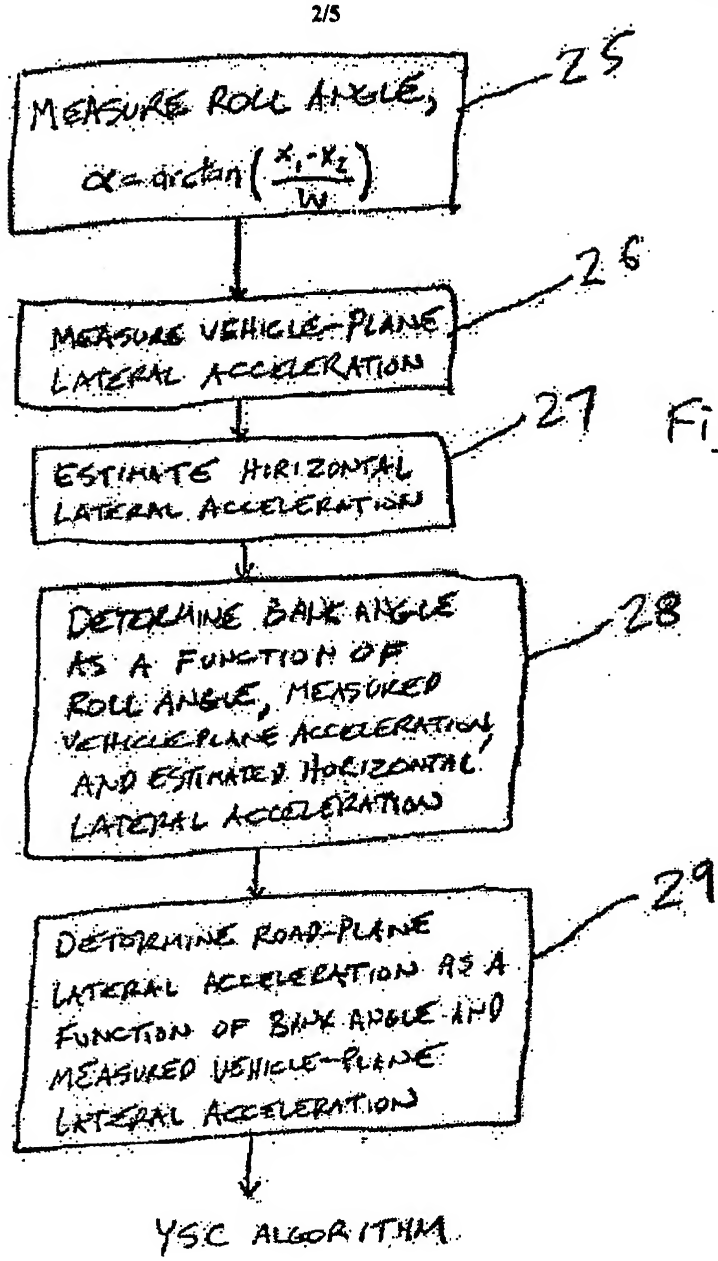

MEASURE ROLL ANGLE,
$\alpha = \arctan\left(\frac{x_1 - x_2}{W}\right)$
25
MEASURE VEHICLE-PLANE LATERAL ACCELERATION
26
ESTIMATE HORIZONTAL LATERAL ACCELERATION
27
DETERMINE BANK ANGLE AS A FUNCTION OF ROLL ANGLE, MEASURED VEHICLE-PLANE ACCELERATION, AND ESTIMATED HORIZONTAL LATERAL ACCELERATION
28
DETERMINE ROAD-PLANE LATERAL ACCELERATION AS A FUNCTION OF BANK ANGLE AND MEASURED VEHICLE-PLANE LATERAL ACCELERATION
29
YSC ALGORITHM

Fig. 3

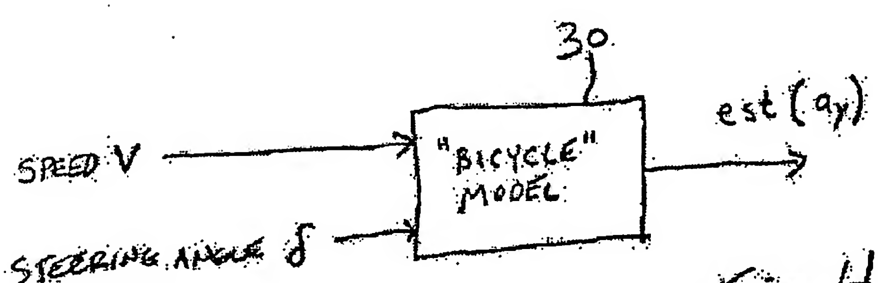
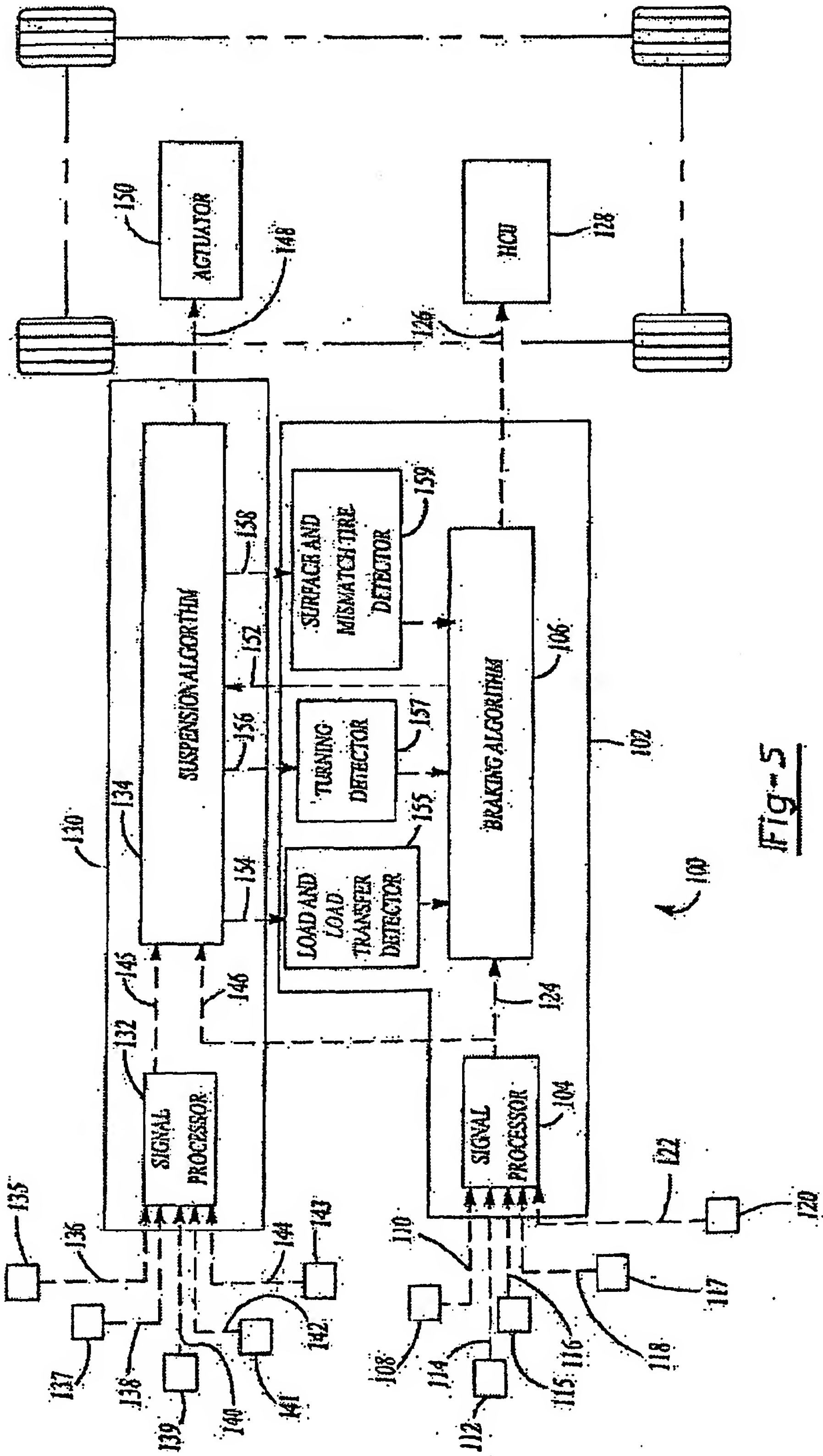

30
SPEED V
STEERING ANGLE δ
"BICYCLE" MODEL
est(a_y)

Fig. 4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TURNING DETECTOR
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156
LOAD AND LOAD TRANSFER DETECTOR
155
154
BRAKING ALGORITHM
106
102
130
134
100
145
146
132
124
SIGNAL PROCESSOR
SIGNAL PROCESSOR
104
122
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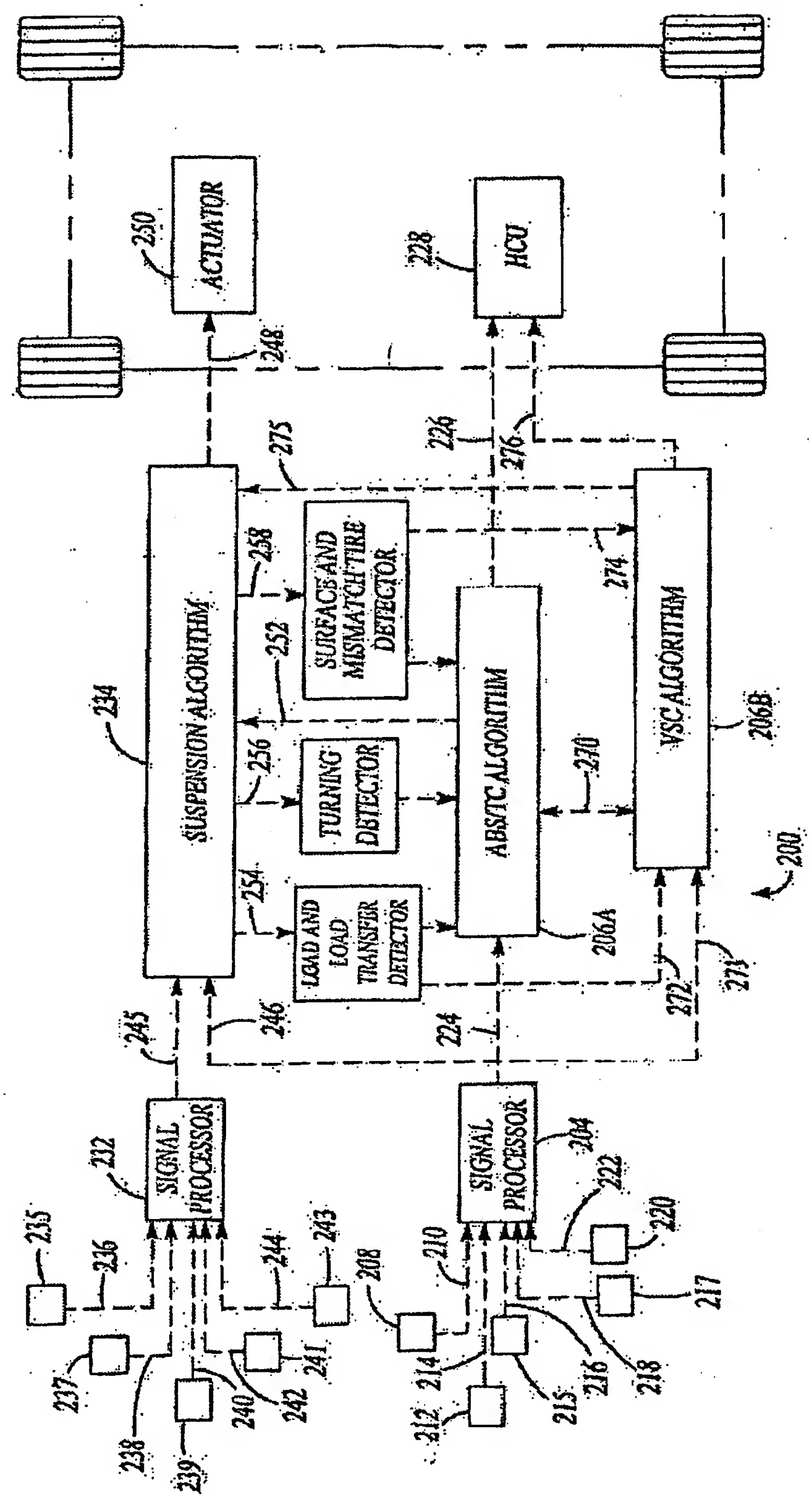
115
116
117
118

Fig-5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HCU
228
226
276
SUSPENSION ALGORITHM
234
275
SURFACE AND MISMATCH TIRE DETECTOR
258
274
252
ABS/TC ALGORITHM
VSC ALGORITHM
206B
TURNING DETECTOR
256
270
LOAD AND LOAD TRANSFER DETECTOR
254
206A
200
272
273
245
246
224
SIGNAL PROCESSOR
232
SIGNAL PROCESSOR
204
235
236
237
238
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220
222

Fig-6

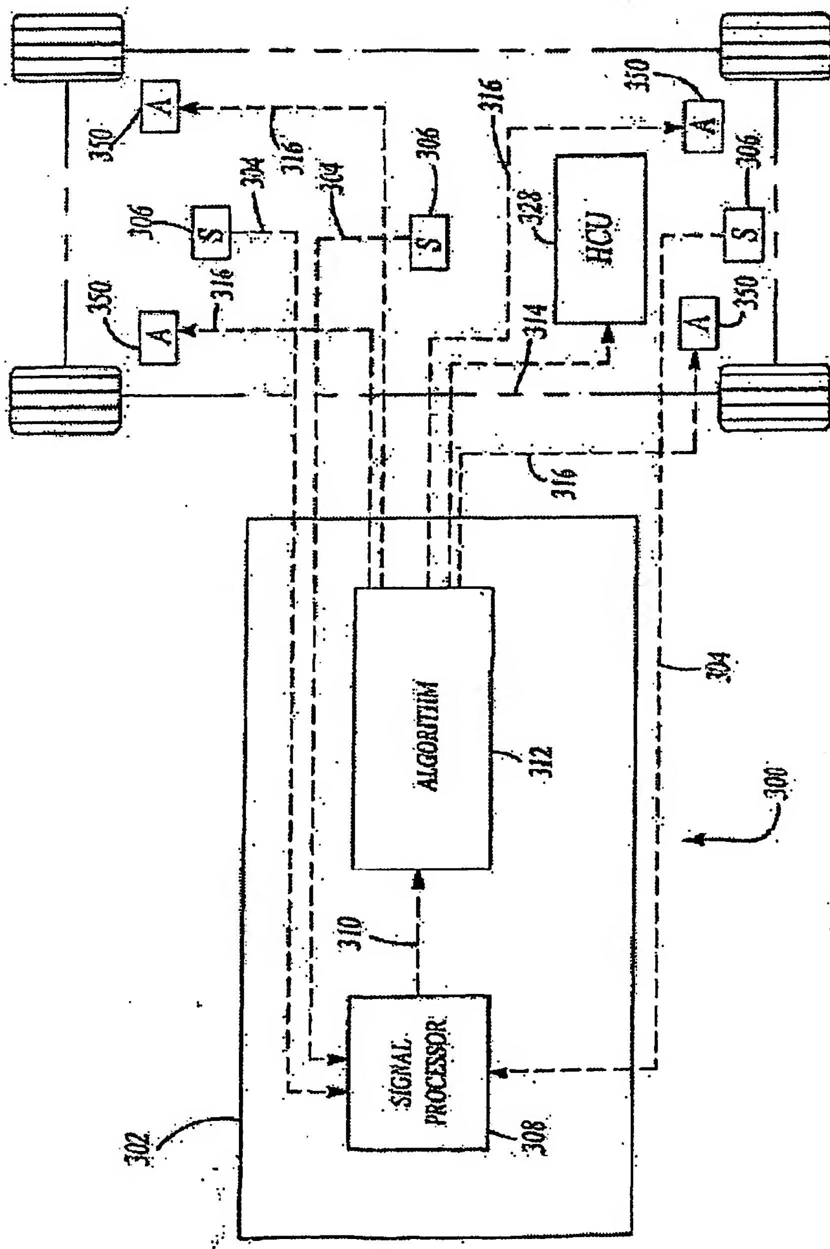
A
S
HCU
ALGORITHM
SIGNAL PROCESSOR
300
302
304
306
308
310
312
314
316
328
350

Fig-7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/28200

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B60T8/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B60T B60G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	DE 42 18 034 A (PORSCHE AG) 9 December 1993 (1993-12-09) page 5, line 14 - line 17	1 2-4
Y A	WO 97 28037 A (GUO LIMIN ;WANKE PETER (DE); ITT MFG ENTERPRISES INC (US)) 7 August 1997 (1997-08-07) The whole document	2,4 8,12
Y	US 5 144 558 A (FUKUSHIMA NAOTO ET AL) 1 September 1992 (1992-09-01) Abstract figure 6	3

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 January 2002	15/01/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Colonna, M

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/28200

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	WO 98 13240 A (BOSCH GMBH ROBERT ;EHRET THOMAS (DE); ZANTEN ANTON VAN (DE)) 2 April 1998 (1998-04-02) Abstract	1,2,4,8, 12

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 01/28200

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
DE 4218034	A	09-12-1993	DE	4218034	A1	09-12-1993
WO 9728037	A	07-08-1997	DE	19607050	A1	07-08-1997
			AU	2083897	A	22-08-1997
			WO	9728037	A1	07-08-1997
			EP	0874750	A1	04-11-1998
			US	6138066	A	24-10-2000
US 5144558	A	01-09-1992	JP	2044190	C	09-04-1996
			JP	7080410	B	30-08-1995
			JP	62295714	A	23-12-1987
			DE	3788594	D1	10-02-1994
			DE	3788594	T2	26-05-1994
			EP	0249246	A2	16-12-1987
WO 9813240	A	02-04-1998	DE	19708508	A1	26-03-1998
			AU	724744	B2	28-09-2000
			AU	3433197	A	17-04-1998
			BR	9706757	A	20-07-1999
			WO	9813240	A1	02-04-1998
			DE	59702683	D1	04-01-2001
			EP	0859712	A1	26-08-1998
			ES	2153205	T3	16-02-2001
			JP	2000501358	T	08-02-2000
			US	6266599	B1	24-07-2001